



Space-Based Range Safety and Future Space Range Applications

*Donald E. Whiteman
NASA Dryden Flight Research Center
Edwards, California*

*Lisa M. Valencia and James C. Simpson
NASA Kennedy Space Center
Kennedy Space Center, Florida*

The NASA STI Program Office...in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

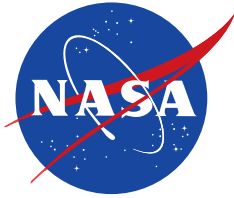
The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.
- **CONFERENCE PUBLICATION.** Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.
- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results...even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at <http://www.sti.nasa.gov>
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA STI Help Desk at (301) 621-0134
- Telephone the NASA STI Help Desk at (301) 621-0390
- Write to:
NASA STI Help Desk
NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320



Space-Based Range Safety and Future Space Range Applications

*Donald E. Whiteman
NASA Dryden Flight Research Center
Edwards, California*

*Lisa M. Valencia and James C. Simpson
NASA Kennedy Space Center
Kennedy Space Center, Florida*

National Aeronautics and
Space Administration

Dryden Flight Research Center
Edwards, California 93523-0273

August 2005

NOTICE

Use of trade names or names of manufacturers in this document does not constitute an official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

Available from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320
301-621-0390

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
703-605-6000

ABSTRACT

The National Aeronautics and Space Administration Space-Based Telemetry and Range Safety study is a multiphase project to demonstrate the performance, flexibility and cost savings that can be realized by using space-based assets for the Range Safety (global positioning system metric tracking data, flight termination command and range safety data relay) and Range User (telemetry) functions during vehicle launches and landings. Phase 1 included flight testing S-band Range Safety and Range User hardware in 2003 onboard a high-dynamic aircraft platform at Dryden Flight Research Center (Edwards, California) using the NASA Tracking and Data Relay Satellite System as the communications link. The current effort, Phase 2, includes hardware and packaging upgrades to the S-band Range Safety system and development of a high data rate Ku-band Range User system. The enhanced Phase 2 Range Safety Unit provided real-time video for three days during the historic GlobalFlyer (Scaled Composites, Mojave, California) flight in March, 2005. Additional Phase 2 testing will include a sounding rocket test of the Range Safety system and aircraft flight testing of both systems. Future testing will include a flight test on a launch vehicle platform. This report discusses both Range Safety and Range User developments and testing with emphasis on the Range Safety system. The operational concept of a future space-based range is also discussed.

NOMENCLATURE

BPF	bandpass filter
C&DH	command and data handler
FTS	flight termination system
GPS	global positioning system
IRIG	Interrange Instrumentation Group
IRIG-B	IRIG timing
LNA	low noise amplifier
LPT	low power transceiver
PN	pseudorandom noise
RCV	receive
RCVR	receiver
RSU	Range Safety Unit
STARS	Space-based Telemetry and Range Safety
TDRSS	Tracking and Data Relay Satellite System
XMT	transmit
XMTR	transmitter

INTRODUCTION

Current space lift launches on the United States Eastern and Western Ranges require extensive ground-based real-time tracking, communications, and command and control systems. These systems are expensive to maintain and operate and are limited to certain geographical areas. Future spaceports will require new technologies to provide greater launch and landing opportunities, support simultaneous missions, and offer enhanced decision support models and simulation capabilities. These ranges must also have lower costs and reduced complexity, while continuing to provide unsurpassed safety to the public, flight crew, personnel, vehicles, and facilities. Commercial and government space-based assets for tracking and communications offer many attractive possibilities to help achieve these goals. Figure 1 shows the current primary Eastern and Western Range instrumentation sites (solid lines) and a possible future space-based configuration with fewer ground-based assets (dashed lines). Note that some launch-head ground-based assets are still planned for visibility and rapid response times shortly after liftoff.

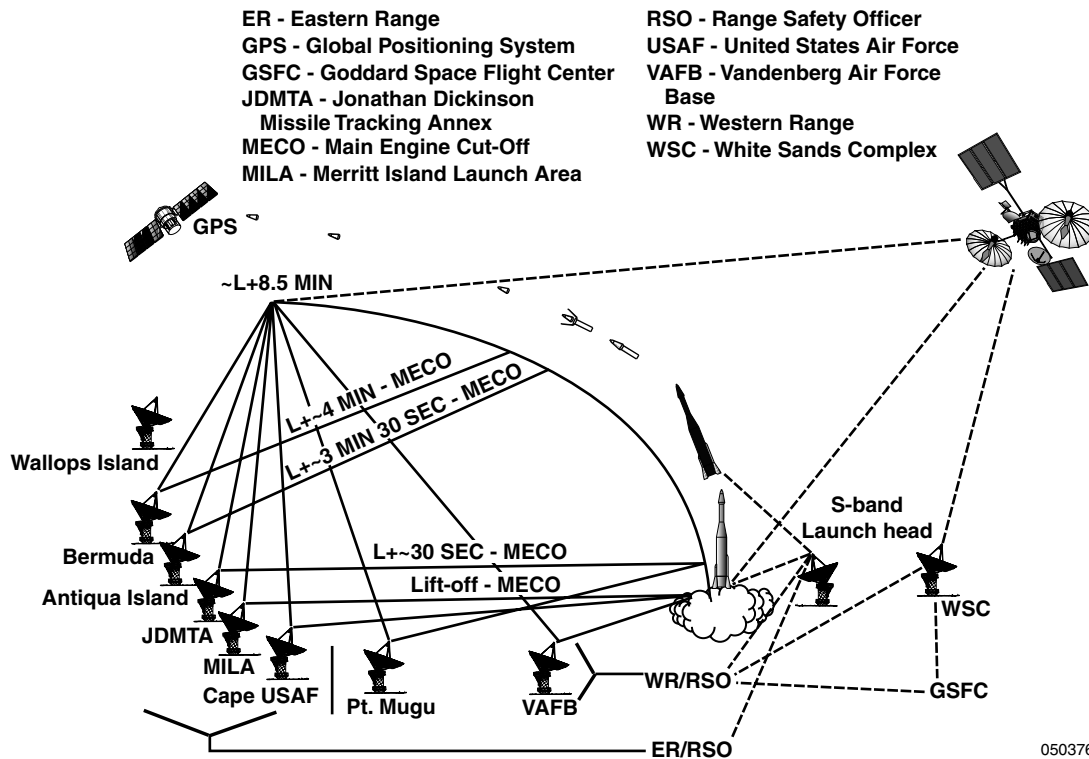


Figure 1. Space-Based Range and Range Safety – today and future.

The National Aeronautics and Space Administration (NASA) Space-Based Telemetry and Range Safety (STARS) study was established to demonstrate the capability of space-based platforms to provide communications for Range Safety (low-rate, ultra-high reliability metric tracking data, and flight termination commands) and Range User (video, voice, and vehicle telemetry) (ref.1). The systems under development and testing include new and improved Range Safety and Range User capabilities and

technologies to support the envisioned future space range. This report concentrates on the low-rate, bidirectional Range Safety system and includes a brief summary of the Range User development effort.

During Phase 1, STARS developed and tested a new S-band Range Safety system. A Range User system representative of those on current launch vehicles was also tested. There were seven test flights on an F-15B aircraft at Dryden Flight Research Center (DFRC) (Edwards, California) during June and July of 2003 (ref. 2). These highly dynamic test flights successfully demonstrated the basic ability of STARS to establish and maintain satellite links with the Tracking and Data Relay Satellite System (TDRSS) and the global positioning system (GPS) and will serve as a baseline for future test flights.

Phase 2 includes enhancements to the S-band Range Safety system as well as a new telemetry system using a Ku-band phased-array antenna to increase the Range User data rates by an order-of-magnitude. Future phases will implement a new Range Safety transceiver system based on current state-of-the-art transceivers and a much smaller, lighter-weight, phased-array Ka-band telemetry antenna on a recoverable hypersonic vehicle. The TDRSS will be the space-based communications link for Phase 2 and future STARS testing.

PHASE 1 RANGE SAFETY SYSTEM

The Phase 1 Range Safety system shown in figure 2 consisted of an S-band low power transceiver (LPT); a GPS receiver and low noise amplifier (LNA); a command and data handler (C&DH) to collect forward link data from the LPT and GPS receiver and format the data for return link transmission; S-band power amplifiers and transmit and receive bandpass filters (BPF); and antennas for TDRSS receive (RCV), TDRSS transmit (XMT), and GPS receive. The Phase 1 configuration is shown in figure 2, and included two sets of TDRSS and GPS antennas located on the top and bottom (indicated by dashed lines) of the aircraft and connected to the rest of the system by hybrid couplers and a power divider.

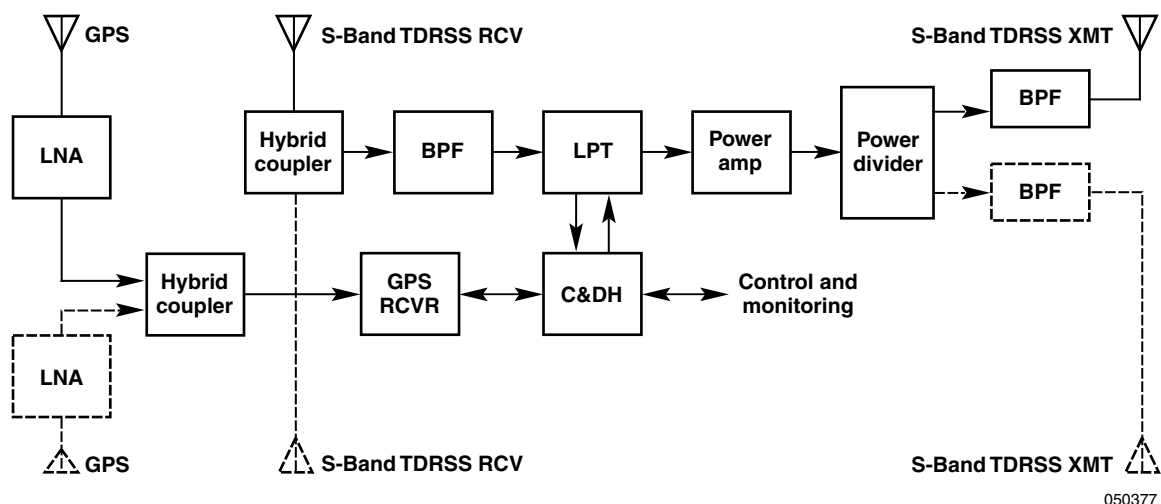


Figure 2. Phase 1 Range Safety system.

The Range Safety forward link was designed to the requirements for an analog flight termination system (FTS) specifying 95 percent spherical coverage and a 12-dB link margin (ref. 3). A digital FTS may have different requirements for comparable performance and reliability.

Figure 3 shows a simplified data flow diagram. In conjunction with the TDRSS link, an S-band launch-head transmit and receive system was used to supplement close-in coverage.

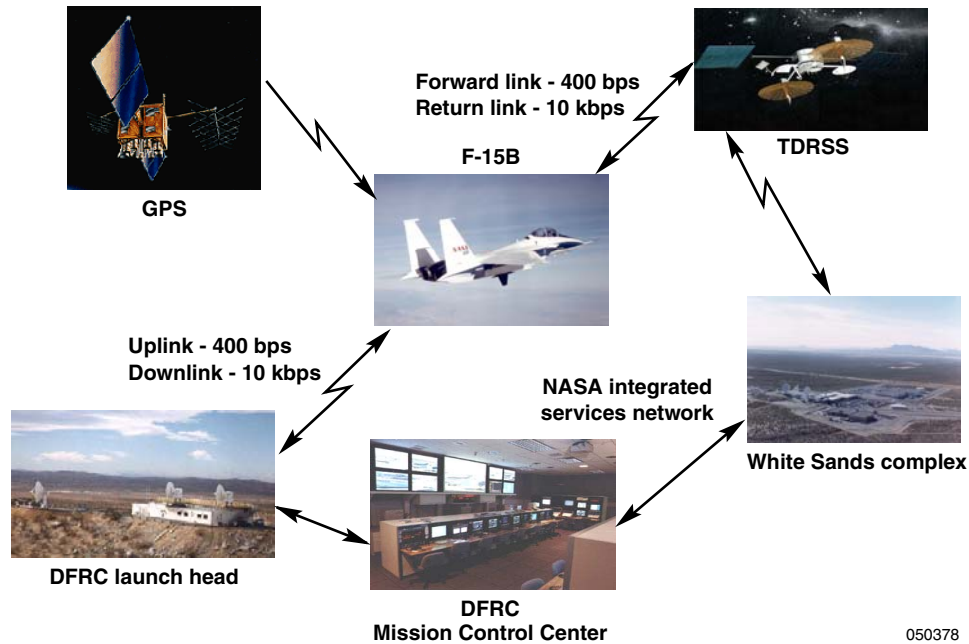


Figure 3. Range Safety data flow.

The launch head and TDRSS forward link used different pseudorandom noise (PN) codes for simultaneous transmission and reception of launch-head and TDRSS links (ref. 4). The LPT includes four receivers: two that receive launch-head PN-encoded data and two that receive TDRSS PN-encoded data. Hybrid couplers allow the in-phase and out-of-phase upper and lower antenna combined outputs to feed each receiver, shown in figure 4.

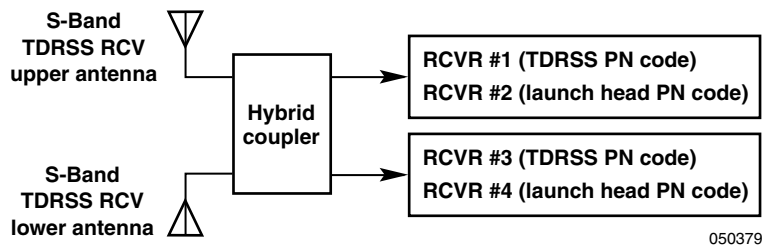


Figure 4. Range Safety system receiver configuration.

The 400-bps forward link data comprise frame synchronization, frame counter, and command word information. The command word system included digital words representing standard analog FTS monitor, arm, and terminate commands. A custom programmable logic device (PLD) design generated the forward link data at the DFRC Mission Control Center. The data were then sent to the launch head and TDRSS forward link transmitters.

The Range Safety return link contained status and data from the LPT, C&DH, and GPS receiver. The data include receiver estimates of the ratio of bit energy to noise power spectral density (E_b/N_0), average Doppler, hardware temperatures, FTS commands received, FTS status, frame synchronization, frame counter, GPS satellite, and GPS receiver performance data.

The initial series of aircraft flight tests were completed in the summer of 2003. Primary objectives were to verify forward link performance during simultaneous transmission and decoding of Range Safety commands by way of both the TDRSS and launch-head links, verification of transition from launch head to TDRSS during over the horizon flights, relay of GPS position information, and quantifying link margins for both the Range Safety forward (command) and return (status) links.

The Range Safety system met the minimum flight test objectives. Hundreds of commands were successfully sent by way of TDRSS and launch-head forward links. These were decoded in the Range Safety system onboard the aircraft and the FTS status and GPS position were successfully monitored by way of the Range Safety return link. The system performed well during highly dynamic maneuvers and all forward link commands sent to the vehicle were successfully interpreted. The system return link margin was approximately 2 to 3 dB less than expected, however, important lessons were learned for Phase 2.

PHASE 2 RANGE SAFETY SYSTEM

The Phase 2 Range Safety system design incorporates lessons learned during the Phase 1 flight tests. The LPT, GPS receiver, and C&DH were integrated into a single unit, shown in figure 5, called the Range Safety Unit (RSU). Encryption was implemented on the forward link and Reed-Solomon encoding was implemented on both forward and return links to enhance bit error rate.



Figure 5. Range Safety Unit.

The RSU system was configured to provide real-time video during the Virgin Atlantic (Sussex, United Kingdom) GlobalFlyer (figure 6) world record flight. The return link data rate was 57 kbps or 114 kbps, depending on available TDRSS link margins, and controlled from switches in the cockpit. The forward link was not used. There was a single S-band antenna on top of the starboard boom of the GlobalFlyer. The system used a video data compressor to convert phase alternation by line (PAL) video to compressed digital video, which was then relayed by way of TDRSS to the White Sands Complex (Las Cruces, New Mexico) and sent over land lines to the GlobalFlyer control room for display and distribution over the Internet. The STARS video was used in conjunction with an Iridium (Bethesda, Maryland) voice link during pilot interviews throughout the mission. The RSU performed well during the nearly three-day flight. There were no environmental problems and the measured Eb/Nos exceeded the predictions by 3 to 5 dB.



Photo courtesy Virgin Atlantic.

Figure 6. GlobalFlyer.

PHASE 1 RANGE USER SYSTEM

The Phase 1 Range User system, shown in figure 7, consisted of an S-band TDRSS transmitter, data multiplexer, power divider, power amplifiers, and two TDRSS transmit antennas located on the top and bottom of the F-15B airplane. The analog video and voice were digitized, compressed, and multiplexed with the pseudorandom data and IRIG-B time inputs (based on Universal Time Coordinated (UTC) derived from GPS time) to create a standard IRIG-106 data stream (refs. 5 and 6). The data multiplexer format was programmable to 125, 250, or 500 kbps; video was included only in the 500-kbps format. The primary objective to transmit vehicle Range User data to the ground by way of TDRSS for relay to DRFC with at least a 3-dB link margin was satisfied.

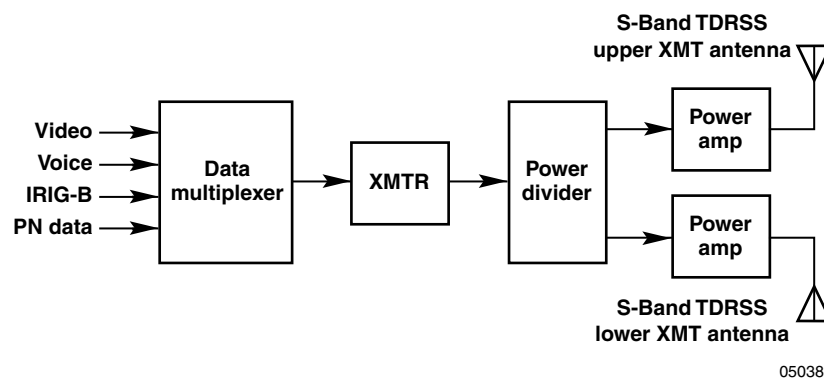


Figure 7. Phase 1 Range User system.

FUTURE PLANS AND CONCLUSIONS

Phase 2 flight testing on a high-performance aircraft is scheduled for 2006 contingent upon funding availability. These tests will measure the system data latency and evaluate the performance of the Range Safety Unit with multiple Tracking and Data Relay Satellites and an updated return-link antenna. A major goal is to determine if a lower link margin with two simultaneous satellite links provides performance equivalent to current analog flight termination systems. A Ku-band phased-array antenna will be used to increase the Range User data rates by an order-of-magnitude.

A sounding rocket test flight of the Phase 2 Range Safety system is currently planned for the fall of 2005. This will be a high-velocity and high-altitude mission to investigate plume effects and the system's performance on a platform representative of an expendable launch vehicle.

The testing to-date indicates that the space-based range safety concept is feasible. Phase 1 flight testing successfully sent and processed over 300 flight termination system commands. Global positioning system metric tracking data was transmitted from the vehicle and received, processed, and displayed at the control center. The Range User telemetry link margins for various data rates met or surpassed the predicted margins. The Phase 2 Range Safety system flown on GlobalFlyer exceeded expectations and demonstrates that the technology has possible additional applications in the area of suborbital vehicles and related air traffic control. These applications could include operations on other celestial bodies including the planned NASA Exploration Mission objectives on the moon and Mars.

The ultimate goal of an operational space-based range is the development and implementation of flexible, reliable, low cost, over the horizon space based range safety systems. NASA and the United States Air Force have been working together through various forums such as the Advanced Range Technologies Working Group to develop roadmaps for the Operational System Design, Development, Concept of Operations, and Range Certification. The development and implementation of the future space-based range concept is critical for expanding government and commercial launch operations in a way that maximizes safety and minimizes related costs thereby enabling the growth of the commercial launch industry.

REFERENCES

1. Whiteman, Don and Robert Sakahara, "Space-Based Telemetry and Range-Safety Study Test Results and Future Operational System Goals," *Proceedings of the International Telemetry Conference*, Las Vegas, NV, October 2003.
2. Kennedy Space Center, "Space-based Telemetry and Range Safety Flight Demonstration #1 Final Report," KSC-YA-6400 Revision Basic, February 10, 2004.
3. Range Commanders Council, U.S. Army White Sands Missile Range, IRIG Standard 319-99, "Flight Termination Systems Commonality Standard," New Mexico, 1999. A copy of this document may be requested from the Secretariat, Range Commanders Council, U. S. Army White Sands Missile Range.

4. Mission Services Program Office, Goddard Space Flight Center, *Space Network Users' Guide (SNUG)*, 450-SNUG, Mission Services Program Office, Goddard Space Flight Center, Revision 8, June 2002.
5. Range Commanders Council, U.S. Army White Sands Missile Range, RCC Standard 200-98, "IRIG Serial Time Code Formats," New Mexico, 1998.
6. Range Commanders Council Telemetry Group, "IRIG Standard 106-04, Part I – Telemetry Standards," published by the Secretariat, Range Commanders Council, U.S. Army White Sands Missile Range, New Mexico, 2004.

REPORT DOCUMENTATION PAGE					Form Approved OMB No. 0704-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</p>						
1. REPORT DATE (DD-MM-YYYY) 31-08-2005		2. REPORT TYPE Technical Memorandum		3. DATES COVERED (From - To)		
4. TITLE AND SUBTITLE Space-Based Range Safety and Future Space Range Applications				5a. CONTRACT NUMBER		
				5b. GRANT NUMBER		
				5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) Donald E. Whiteman, Lisa M. Valencia, and James C. Simpson				5d. PROJECT NUMBER		
				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER ESE		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NASA Dryden Flight Research Center P.O. Box 273 Edwards, California 93523-0273				8. PERFORMING ORGANIZATION REPORT NUMBER H-2616		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSORING/MONITOR'S ACRONYM(S) NASA		
				11. SPONSORING/MONITORING REPORT NUMBER NASA/TM-2005-213662		
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified -- Unlimited Subject Category 17 Availability: NASA CASI (301) 621-0390						
13. SUPPLEMENTARY NOTES An electronic version can be found at the NASA Dryden Flight Research Center Web site, under Technical Reports.						
14. ABSTRACT The National Aeronautics and Space Administration Space-Based Telemetry and Range Safety study is a multiphase project to demonstrate the performance, flexibility and cost savings that can be realized by using space-based assets for the Range Safety (global positioning system metric tracking data, flight termination command and range safety data relay) and Range User (telemetry) functions during vehicle launches and landings. Phase 1 included flight testing S-band Range Safety and Range User hardware in 2003 onboard a high-dynamic aircraft platform at Dryden Flight Research Center (Edwards, California) using the NASA Tracking and Data Relay Satellite System as the communications link. The current effort, Phase 2, includes hardware and packaging upgrades to the S-band Range Safety system and development of a high data rate Ku-band Range User system. The enhanced Phase 2 Range Safety Unit provided real-time video for three days during the historic GlobalFlyer (Scaled Composites, Mojave, California) flight in March, 2005. Additional Phase 2 testing will include a sounding rocket test of the Range Safety system and aircraft flight testing of both systems. Future testing will include a flight test on a launch vehicle platform. This report discusses both Range Safety and Range User developments and testing with emphasis on the Range Safety system. The operational concept of a future space-based range is also discussed.						
15. SUBJECT TERMS GlobalFlyer, Range safety, Space-based range, Space-based Telemetry and Range Safety, TDRSS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk (email: help@sti.nasa.gov)	
U	U	U	UU	14	19b. TELEPHONE NUMBER (Include area code) (301) 621-0390	